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COMPUTATION OF IMAGINARY-SIDE PRESSURE DISTRIBUTIONS OVER THE FLEXIBLE WALLS OF THE TEST SECTION INSERT FOR THE 0.3-M TRANSONIC CRYOGENIC TUNNEL

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CONTENTS

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1. INTRODUCTION.

The object is to provide a method for determining the pressure distribution along the flexible walls of the 13 inch insert for the 0.3m Cryogenic Pressure Tunnel. The program IFLEX, the subject of this report, provides a method for general wall shapes. The program is based on incompressible potential flow theory, with the addition of an allowance for compressibility effects through the Prandtl-Glauert factor.

The program is quite compact, suitable for mini and micro computers, and is presented in BASIC language.

The essence of the method is to create mathematically an artificial flowfield which contains a streamline springing from infinity having the same shape as a wall. To one side of this streamline, corresponding to the imaginary-flow side of a flexible wall, there are no singularities, and the velocity distribution along the streamline is that which would exist in a semi-infinite inviscid flowfield over that side of the flexible wall. The input data is therefore the wall shape. The flowfield comprises a free stream influenced by a set of sources and sinks positioned regularly along a line parallel to the free stream. The source line is a tangent to the wall at its closest point to the axis of the test section. Often this tangent will in fact pass through the wall anchor point, jack zero, simply because the wall is everywhere else further away.

The input data comprises a set of wall deflections from "straight", measured at jacks. In the context of this work, "straight" must be interpreted as aerodynamically straight as defined in NASA CR-165936.

The strength of the source/sink set is adjusted until a streamline passes through the defined wall co-ordinates given

by the movement of jacks. The first source/sink is positioned $^3/_4$" downstream of the anchor point (the upstream fixed end of the wall) the remainder being spaced at regular $1\frac{1}{2}$" intervals downstream. The velocity/pressure coefficient is determined at "computing points" on the wall mid-way (measured streamwise) between sources, that is at regular $1\frac{1}{2}$" intervals downstream from the anchor point.

The nature of the wall shape and jack spacing suggests the adoption of the following policy. Refer to test section drawing LD-525722 for relevant wall dimensions. There is a slope discontinuity built into the walls near to jack 19. The influence of the discontinuity on the static pressure at this jack station will cause the wall to be driven to an unrealistic position. The wall will be driven outwards in the subsonic flow normally expected in this region. It is suggested that in streamlining the walls (empty, or with a model present) the real-side pressure at jack 19 be ignored, and the jack be driven to position the wall at a point given by an extrapolation of the wall line through jacks 17 and 18. In this way the influence of the discontinuity on events at jack 18 will be minimised. Following this, the program to determine the pressures over the imaginary sides of the walls need only account for the movements of jacks 1 to 18 (jack 0 being the anchor point), with a small straight extrapolation towards the position of jack 19.

This arrangement results in the creation of many more sources and "computing points" than there are jacks, although many of the jacks do coincide with computing points particularly in the region of the model. Appendix 1 clarifies the positions of devices along a wall. The station measurements coincide with those on drawing LD-525722. The station of jack 0 is not definable exactly. It is taken as 0.5".

The two walls almost always have different shapes: they are therefore computed separately.

2. NOTES ON THE PROGRAM IFLEX.

The listing, given as Appendix 2, has many built-in comments aimed at clarifying the details of computation. These notes supplement that source of information.

The steps in the program comprise:

interpolation between jack displacements to give wall displacements at each of 34 computing points

adjustment of source/sink strengths until a streamline passes through the 34 points

computation of pressure coefficients at computing points

linear interpolation to give pressure coefficients at jacks which lie between computing points.

Built into the program is a demonstration case: each wall is given a sinusoidal wave displaced upward. The wave is 20" long, $\frac{1}{2}$" peak height. The imaginary flow above the top wall flows over what could be described as a $\frac{1}{2}$" high "ridge" transverse to the free stream. As the wall is in some places not moved from its straight position, and is elsewhere raised above the straight, the sources lie along the "straight" position because this is also the tangent to the point (in this case in two areas) nearest to the tunnel axis.

The imaginary flow for the bottom wall traverses a "valley". The sources lie along a line displaced into the test section by the wave height, $\frac{1}{2}$". These geometries result in the appearance of a positive-negative-positive Cp sequence in the imaginary field outside of the top wall, with the strongest negative at the ridge crest. There is the opposite effect on the bottom wall. The output for this demonstration case is given in Appendix 3.

The program adopts linear extensions of the walls for $4\frac{1}{2}$" beyond jack 18. The bend in the wall is 4.3" beyond jack 18.

4. A POTENTIAL-FLOW TEST CASE.

In order to check quantitatively on the output from the program, a potential-flow test case has been generated. The small program in Appendix 4 computes the shape and pressure

distribution along a streamline in the appropriate position for a wall. The streamline passes by a body created by a single source. A sketch is given on figure 1, which also has a plot of the shape of the streamline and its pressure distribution. The shape was used as input data to IFLEX, in the form of streamline deflections inline with each jack station. On the same plot is the exact pressure distribution compared with the predictions from IFLEX.

The two sets of pressure coefficient data are seen to be in close agreement. The maximum error in IFLEX is about ± 0.002, likely to be compatible with the precision of the measurements of corresponding real-side pressures in the test section. One reason for IFLEX predicting a higher C_p near to the anchor point is the change in boundary slope which is assumed by IFLEX to occur near to the anchor point. No similar slope change occurs in the potential flow model.

The program is easily adapted in the manner indicated in its inbuilt comments to take as input data, if desired, the shapes of walls selected in wind tunnel tests. The computing time in BASIC on an HP 9845 is a total of 3 minutes for two walls including output as hard copy.

APPENDIX 1

IMAGINARY FLOWFIELD COMPUTATIONS
FLEXIBLE WALL INSERT FOR 0.3m

POSITION TABLE

Station inches	Jack#	Source#	Computing point
.50	0		0
1.25		0	
2.00			1
2.75		1	
3.50			2
4.25		2	
4.75	1		
5.00			3
5.75		3	
6.50			4
7.25		4	
8.00			5
8.75		5	
9.50			6
10.25		6	
10.50	2		
11.00			7
11.75		7	
12.50			8
13.25		8	
14.00			9
14.75		9	
15.50	3		10
16.25		10	
17.00			11
17.75		11	
18.50			12
19.25		12	
19.50	4		
20.00			13
20.75		13	
21.50			14
22.25		14	
22.50	5		
23.00			15
23.75		15	
24.50	6		16
25.25		16	
26.00	7		17
26.75		17	

27.50	8		18
28.25		18	
29.00	9		19
29.75		19	
30.50	10		20
31.25		20	
32.00	11		21
32.75		21	
33.50	12		22
34.25		22	
35.00			23
35.50	13		
35.75		23	
36.50			24
37.25		24	
37.50	14		
38.00			25
38.75		25	
39.50	15		26
40.25		26	
41.00			27
41.75		27	
42.50	16		28
43.25		28	
44.00			29
44.75		29	
45.50			30
46.25		30	
46.50	17		
47.00			31
47.75		31	
48.50			32
49.25		32	
50.00			33
50.75		33	
51.50	18		34

```
10  !  RE-SAVEd as "IFLEX"
20  PRINTER IS 0
30  OPTION BASE 0
40  PRINT
50  PRINT "          WALL IMAGINARY-SIDE PRESSURE COEFFICIENTS".
60  PRINT "          -----------------------------------------"
70  PRINT "  FOR FLEXIBLE WALLED INSERT IN 0.3m CRYOGENIC WIND TUNNEL."
80  PRINT "  -----------------------------------------------------------"
90  PRINT "                          IFLEX"
100 PRINT "                       August 6, 1982"
110   PRINTER IS 16
120 DIM Ty(18),By(18)        ! Jack displacements from aerodynamically straight,
130                          !   positive AWAY from test section centerline.
140 DIM Buf(18)              ! Buffer store for jack displacements.
150                          ! Dimensions are inches.
160 DIM Bufi(37)             ! Buffer store for interpolated wall displacements.
170 DIM A(37,37),S(36)       ! A for (source-wall angles)/PI, S for sources.
180 DIM Cp(36)               ! Pressure coefficients at computing points."
190 DIM X(18)                ! Streamwise stations of jacks.
200 DIM Di(18)               ! Used only in generating a set of prog. test data.
210   DATA 0.5,4.75,10.5,15.5,19.5,22.5,24.5,26,27.5,29,30.5,32,33.5,35.5,37.5
220   DATA 39.5,42.5,46.5,51.5       ! Jack stations.
230   Mo=0                   ! Reference Mach nr.
240   IF Mo<.9 THEN 280
250   INPUT "Mach may be too high.  Input P[CONT] if to proceed:",P$
260   IF P$="P" THEN 280
270   GOTO 250
280   Beta=SQR(1-Mo*Mo)         ! Prandtl-Glauert factor.
290   FOR K=0 TO 18
300   READ X(K)
310   Di(K)=0
320   NEXT K
330   FOR J=4 TO 14 STEP 1  ! Jack nr.
340   Di(J)=.25+.25*SIN((X(J)-24.0)*PI/10) ! Sinusoid test case. Wave .5" high
350   NEXT J             ! and 20" wavelength centered on jack 9 at station 19".
360   FOR I=0 TO 18 STEP 1  ! Change of sign in lines 380 or 390 will exchange
370   !   ridge for valley.
380   Ty(I)=Di(I)     ! For top wall this wave is a ridge: negative Cp on crest.
390   By(I)=-Di(I)    ! "   bottom "   "    "     " " valley: pos.    "  in hollow
400   NEXT I          ! Test case formed.
410   !   The programme proper starts here.Ty() & By() must already be loaded.
420   Co=0         ! Zero when computing top wall, & set to 1 for bottom wall.
430   GOTO 490
440   FOR Ii=0 TO 18
450   Buf(Ii)=By(Ii)        ! Load buffer store with bottom y-coordinates.
460   NEXT Ii
470   Yy=0
480   GOTO 520
490   FOR B=0 TO 18
500   Buf(B)=Ty(B)          !   "     "     "     "    top      "
510   NEXT B
520   X=.5          ! X is to be raised from this value in 1.5" increments.
530   N1=0
540   Bufi(0)=0     ! Zero displacement at sta. 0.5 inch.
550   Y=0
560   N9=3          ! First jack # which coincides with the chosen X-spacing.
570   Xc=X(N9)
580   FOR N=0 TO 15 STEP 1
590   X1=X(N)
600   X2=X(N+1)
610   X3=X(N+2)
620   X4=X(N+3)
630   Y1=Buf(N)
640   Y2=Buf(N+1)
650   Y3=Buf(N+2)
660   Y4=Buf(N+3)
```

```
670   GOSUB 2090
680   X=X+1.5                ! Next station at which interpolation to be made.
690   N1=N1+1                ! Counter for nr. of stations interpolated.
700   IF N<15 THEN 720       ! Go if not interpolating between jacks 16-18.
710   GOTO 730
720   IF X>X3 THEN 800       ! Most times interp. only in center patch.
730   Y=Y4+A2*(X-X4)^3+B2*(X-X4)^2+C2*(X-X4)   ! Interpolated displacement.
740   IF X>51.5 THEN 1050 ! No interest beyond jack 18.
750   Bufi(N1)=Y             ! Interpolated wall displacement.
760   IF Y<Yy THEN 900       ! Search for the minimum Y.
770   IF X=Xc THEN 830       ! Sta. X coincides with a jack.
780   IF X>Xc THEN 870       ! Bypassed a jack. Go to make Xc the next jack's sta.
790   GOTO 680
800   N1=N1-1
810   X=X-1.5
820   NEXT N
830   N9=N9+1
840   IF N9>18 THEN 920
850   Xc=X(N9)
860   GOTO 790
870   N9=N9+1                ! Jack counter.
880   Xc=X(N9)
890   GOTO 790
900   Yy=Y
910   GOTO 770
920   Bufi(35)=2*Bufi(34)-Bufi(33) ! One interval (1.5") extension in st. line.
930   Bufi(36)=2*Bufi(35)-Bufi(34) !          "
940   Bufi(37)=2*Bufi(36)-Bufi(35) !          "
950   FOR K1=0 TO 37
960   Bufi(K1)=Bufi(K1)-Yy   ! Displacements are now all relative to a source
970                          !  line passing through the point on the wall
980                          !  closest to the centerline of the test section.
990    NEXT K1
1000   !                        Start of aerodynamics.
1010   !                           Linearized.
1020   FOR A1=0 TO 36
1030   S(A1)=Bufi(A1+1)-Bufi(A1)          ! 34 approximate source half-strengths.
1031   S(A1)=S(A1)*(1+.75*Bufi(A1+1))
1040   NEXT A1
1050   PRINT
1060   IF Co=1 THEN 1090
1070   PRINT "      Computing & correcting source/sink strengths for top wall:"
1080   GOTO 1110
1090   PRINTER IS 16
1100   PRINT "       Computing source/sink strengths for bottom wall:"
1110   PRINT "                    - 2 iterations -"
1120   PRINT "                 Pass 1    (slow- 35 secs)"
1130   FOR P7=1 TO 2                   ! Pass number, correcting sources.
1140   F6=-Yy
1150   FOR N=1 TO 37 STEP 1            ! Interval number.
1160   F2=Bufi(N)                      ! Free stream contribution to SF.
1170   FOR P=0 TO 36                   ! Sources in turn.
1180   IF P=N-1 THEN 1250              ! Miss out the source just upstream.
1190   IF P7>1 THEN 1230
1200   T=Bufi(N)/(1.5*(N-P-.5))
1210   IF ABS(T)<.05 THEN 1430         ! Assume Tan(small angle) = angle,
1220   A(N,P)=ATN(T)/PI                !             to speed up computation.
1230   F5=S(P)*A(N,P)                  ! SF contribution from this source.
1240   F2=F2+F5       ! Sum all source flow contributions to stream function SF.
1250   NEXT P
1260   IF P7>1 THEN 1300
1270   T=4*Bufi(N)/3 ! Tangent of angle between point on wall & source just U/S
1280   IF ABS(T)<.05 THEN 1450
1290   A(N,N-1)=ATN(T)/PI
1300   S(N-1)=(F2-F6)/(1-A(N,N-1))      ! Adjust source to equalise SF's.

1310   F6=F6+S(N-1)                     ! SF for next N.
1320   NEXT N
```

```
1330   IF P7=5 THEN 1360
1340   PRINT "                        Pass";P7+1;"   (11 secs)"
1350   NEXT P7
1360   GOTO 1470                          ! Unless you would like the sources.
1370   PRINT
1380   PRINT "Station         Source strength      Source#"
1390   FOR Nh=0 TO 36
1400   PRINT USING 2060;Nh*1.5+1.25,2*S(Nh),Nh
1410   NEXT Nh
1420   GOTO 1470
1430    A(N,P)=T/PI
1440    GOTO 1230
1450   A(N,N-1)=T/PI
1460   GOTO 1300
1470    PRINT
1480    PRINT "            Have sources."
1490    PRINT "            Computing Cp's..."
1500    GOTO 1590             ! But there is the option of printing Cp at
1510                          !  1.5" intervals by not going to 1590.
1520    PRINT
1530    IF Co=1 THEN 1560
1540    PRINT "            TOP WALL"
1550    GOTO 1570
1560    PRINT "           BOTTOM WALL"
1570    PRINT "Station","Cp"
1580    PRINT
1590    FOR Q=0 TO 34         ! Computing point. Station is .5+1.5*Q
1600    C7=0                  ! See separate notes.
1610    C8=0
1620    FOR R=0 TO 36         ! Sources in turn.
1630    T1=(Q-R-.5)*1.5       ! Streamwise distance from source to point.
1640    T2=S(R)*T1
1650    T3=Bufi(Q)*Bufi(Q)+T1*T1
1660    T4=T2/T3
1670    C7=C7+T4
1680    T5=S(R)*Bufi(Q)
1690    T6=T5/T3
1700    C8=C8+T6
1710    NEXT R
1720    C7=C7/PI
1730    C8=C8/PI
1740    C9=(-2*C7-C7*C7-C8*C8)/Beta
1750    Cp(Q)=C9              ! Cp.
1760    GOTO 1780             ! But not if you want Cp at 1.5".
1770    PRINT USING 2070;Q*1.5+.5,C9
1780    NEXT Q
1790    PRINT
1800    PRINTER IS 0
1810    IF Co=1 THEN 1840
1820    PRINT "                Top wall"
1830    GOTO 1850
1840    PRINT "               Bottom wall"
1850    PRINT
1860    PRINT "           Jack         Cp"
1870    FOR E=1 TO 18         ! Cp at jacks by linear interpolation.
1880    X=X(E)
1890    FOR G=0 TO 34
1900    X1=.5+G*1.5
1910    IF X1>=X THEN 1930
1920    NEXT G
1930    Cpa=Cp(G-1)
1940    Cpb=Cp(G)
1950    Cp=Cpa+(Cpb-Cpa)*(X-X1+1.5)/1.5
1960    PRINT USING 2080;E,Cp
1970    NEXT E
1980    PRINT
```

```
1990    PRINT
2000    IF Co=1 THEN 2030
2010    Co=1
2020    GOTO 440
2030    PRINT
2040    PRINT
2050    END
2060    IMAGE DD.DD,13X,D.DDDDD,13X,DD
2070    IMAGE DD.D,13X,D.DDDD
2080    IMAGE 10X, DD,6X,MDD.DDDD
2090    X5=X3-X4
2100    X6=X2-X4
2110    X7=X1-X4
2120    Y5=Y3-Y4
2130    Y6=Y2-Y4
2140    Y7=Y1-Y4
2150    B1=X5*X5-X5*X5*X5/X6
2160    B3=X7*X7-X7*X7*X7/X6
2170    C1=X5-X5*X5*X5/(X6*X6)
2180    C3=X7-X7*X7*X7/(X6*X6)
2190    Z1=Y5-Y6*(X5*X5*X5)/(X6*X6*X6)
2200    Z3=Y7-Y6*(X7*X7*X7)/(X6*X6*X6)
2210    C2=Z1*B3/B1-Z3
2220    C2=C2/(C1*B3/B1-C3)
2230    B2=(Z1-C2*C1)/B1
2240    A2=(Y5-B2*X5*X5-C2*X5)/(X5*X5*X5)
2250    RETURN
```

APPENDIX 3

WALL IMAGINARY-SIDE PRESSURE COEFFICIENTS

FOR FLEXIBLE WALLED INSERT IN 0.3m CRYOGENIC WIND TUNNEL.

IFLEX
August 6, 1982
Top wall

Jack	Cp
1	.0060
2	.0108
3	.0165
4	.0747
5	.0383
6	-.0483
7	-.1245
8	-.1823
9	-.2038
10	-.1823
11	-.1246
12	-.0486
13	.0395
14	.0806
15	.0555
16	.0220
17	.0126
18	.0072

Bottom wall

Jack	Cp
1	-.0055
2	-.0097
3	-.0110
4	-.0782
5	-.0254
6	.0656
7	.1243
8	.1605
9	.1725
10	.1605
11	.1244
12	.0659
13	-.0261
14	-.0841
15	-.0543
16	-.0188
17	-.0114
18	-.0064

```
10    ! Potential flow streamline : source in uniform flow. Source strength
20    !  chosen such that body thickness is T" far downstream. The streamline
30    !  deflections which the programme gives apply to a line which passes
40    !  through a point 6.5" above the centerline (on which the source is
50    !  located,inline with jack 9) at station 0.5", that is at the anchor
60    !  point jack 0.  Program POT. X-Y axis origin is at source.
70    DIM X(18)
80    INPUT "Thickness of body far downstream,inches",T
90    DATA 4.75,10.5,15.5,19.5,22.5,24.5,26,27.5,29,30.5,32,33.5,35.5,37.5
100   DATA 39.5,42.5,46.5,51.5
110   PRINT "                ";T;"INCH BODY."
120   PRINT "JACK     STATION      DEFLECTION         Cp"
130   FOR J=1 TO 18
140   READ X(J)
150   Yo=6.5
160   X=X(J)-29
170   F=6.5+ATN(6.5/-28.5)*T/(2*PI)
180   IF X=0 THEN 360
190   IF X<0 THEN 210
200   F=6.5+ATN(6.5/-28.5)*T/(2*PI)+T/2
210   FOR Y=Yo TO 10 STEP .04
220   F1=Y+T*ATN(Y/X)/(PI*2)
230   IF F1>F THEN 250
240   NEXT Y
250   Y1=Y
260   FOR Y=Y1 TO 0 STEP -.001
270   F1=Y+T*ATN(Y/X)/(PI*2)
280   IF F1<F THEN 300
290   NEXT Y
300   Y1=Y
310   FOR Y=Y1 TO 10 STEP .0001
320   F1=Y+T*ATN(Y/X)/(PI*2)
330   IF F1>F THEN 370
340   NEXT Y
350   GOTO 370
360   Y=F+T/4          !  Y in closed form above origin.
370   R=X*X+Y*Y        !  R^2!
380   C=-(T*X)/(PI*R)-(T*X/(2*PI*R))^2-(T*Y/(2*PI*R))^2
390   PRINT USING 440;J,X+29,Y-Yo,C
400   NEXT J
410   PRINT
420   PRINT
430   END
440   IMAGE DD, 7X, DD.DD, 7X,DD.DDDD, 7X,DD.DDDDD
```

2 INCH BODY.

JACK	STATION	DEFLECTION	Cp
1	4.75	.0122	.02433
2	10.50	.0368	.03033
3	15.50	.0729	.03767
4	19.50	.1225	.04434
5	22.50	.1831	.04644
6	24.50	.2413	.04207
7	26.00	.2964	.03277
8	27.50	.3602	.01731
9	29.00	.4286	-.00211
10	30.50	.4959	-.02063
11	32.00	.5566	-.03421
12	33.50	.6083	-.04191
13	35.50	.6632	-.04531
14	37.50	.7049	-.04440
15	39.50	.7366	-.04173
16	42.50	.7714	-.03698
17	46.50	.8028	-.03126
18	51.50	.8284	-.02576

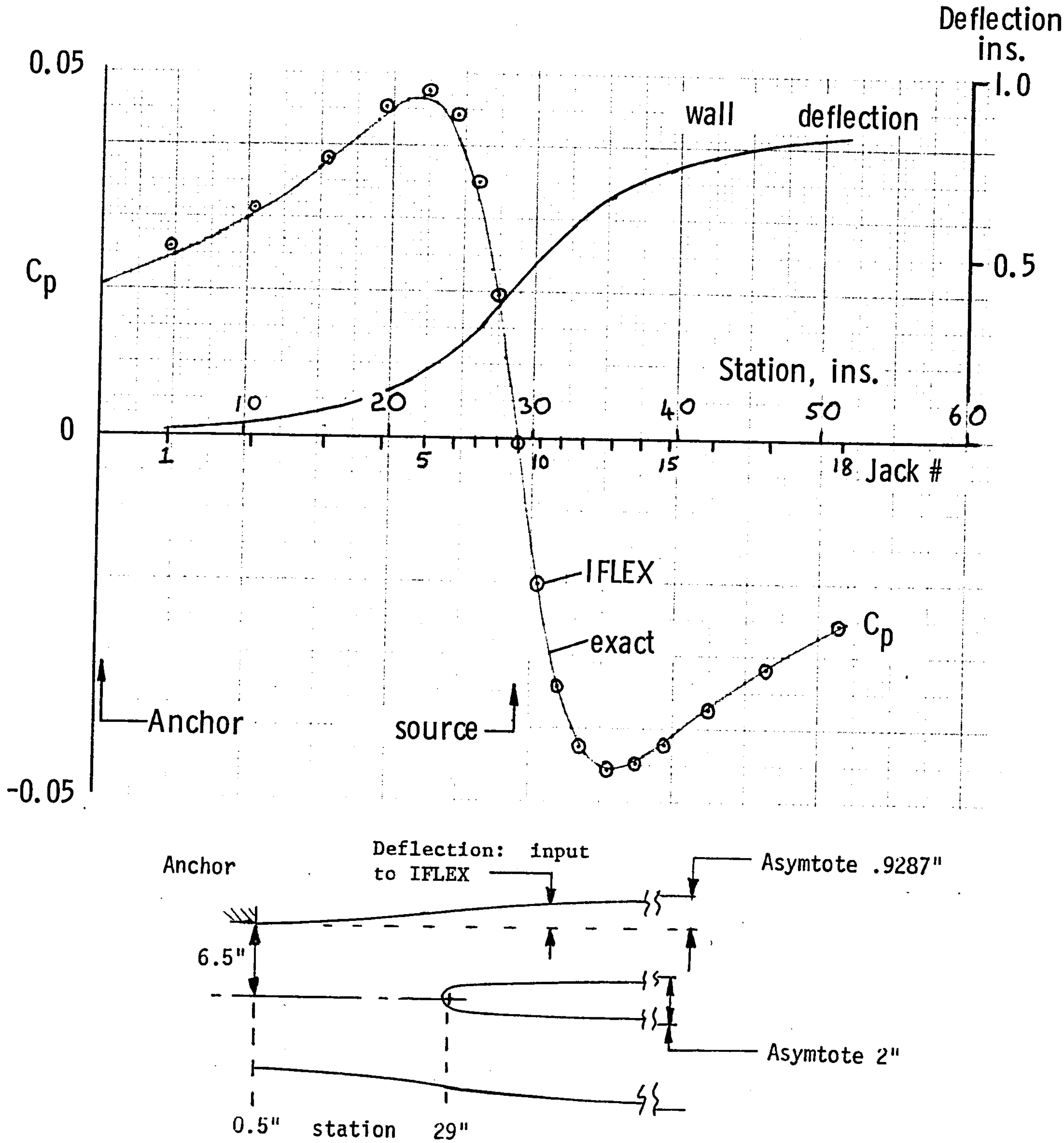

Figure I. Test case and comparison between exact and IFLEX values of pressure coefficient.

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15. Supplementary Notes

*University of Southampton

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16. Abstract

Two dimensional airfoil testing in an adaptive wall test-section wind tunnel requires the computation of the imaginary flow fields extending outward from the top and bottom test section walls. A computer program was developed to compute the flow field which would be associated with an arbitrary test section wall shape. The program is based on incompressible flow theory with a Prandtl-Glauert compressibility correction. The program was validated by comparing the streamline and the pressure field generated by a source in uniform flow with the results from the computer program. A listing of the program, the validation test results, and a sample program are included.

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